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(54) Title: MULTIPLE ANTENNA HOME BASE FOR DIGITAL CORDLESS TELEPHONES

BASE STATION RECEIVER STRUCTURE
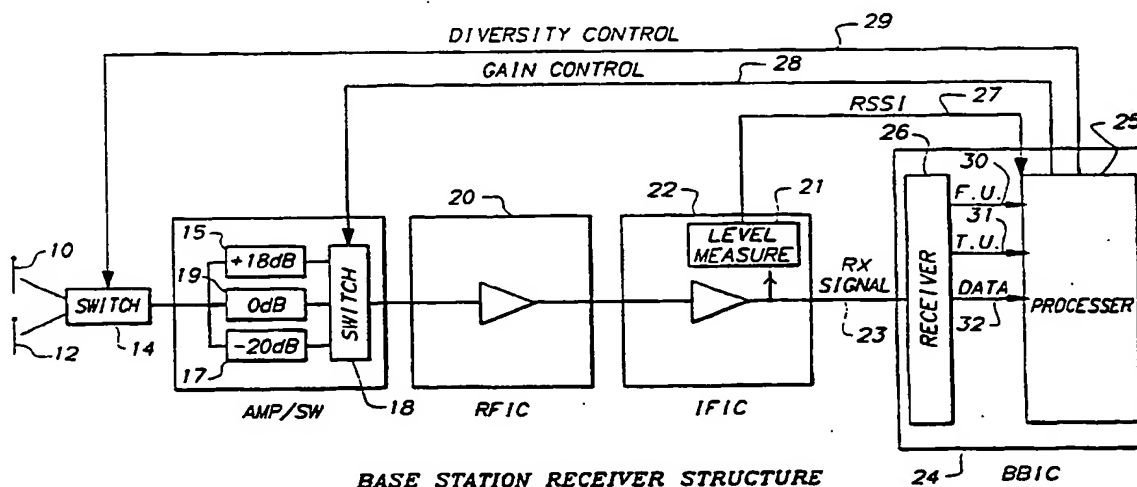
(57) Abstract

The present invention provides methods for combining antenna diversity (10, 12) and gain control (15, 19, 17) in a communications system using a single chain of receiver characteristics. A number of input parameters related to various characteristics of a received signal are used to determine the quality of the received signal. The antenna diversity and gain control procedures are enabled or disabled based on the signal quality. The antenna diversity procedure estimates the signal level of the non-operational antenna using an infinite impulse response digital filter. The gain control procedure selects one of three gain paths based on the received signal strength.

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MULTIPLE ANTENNA HOME BASE FOR DIGITAL CORDLESS TELEPHONES

Field of the Invention

The present invention is directed to methods of combining antenna diversity and gain control in a
5 communications system. More particularly, the invention is directed to methods of antenna diversity and gain control in a communications system using Time Division Duplexing and having multiple antennas with single receive channel electronics.

10 ## Background

An advanced digital cordless telephone (DCT) system uses digital, time divided, transmissions referred to as TDD (time division duplexing). The transmissions occur between one or more portable hand held units (typically pedestrians
15 or persons moving around in an office building) and a base station which serves a defined geographic area known as a cell. A typical operational frequency for a DCT is in the vicinity of 2000 MHz. The base station typically transmits a burst of data every 5 milliseconds and the portable handheld
20 unit transmits back a burst of data about 2.5 milliseconds after the base station transmits. Both units transmit at the same frequency, and transmit bursts are typically about 625 microseconds (including guard time) as shown in Figure 1. Based on these timing constraints the DCT system can provide
25 four channels so that four communications links can be established between four portable units and the base station. Each of the portable units is assigned one of the 625 μsec. slots in each of the 2.5 msec. receive and transmit windows.

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In an urban or indoor environment there is significant multipath effect with transmissions at this frequency range, which manifests itself as Rayleigh fading of the received signal level. One technique used to minimize
5 this problem is known as diversity. The underlying idea behind diversity, as an antidote to Rayleigh fading, is that if one is able to obtain reception via two (or more) independent paths then it is unlikely that both (or all) of these paths will fade simultaneously. These independent
10 paths may be obtained by diversity in time, frequency, or space. Since the DCT operates in TDD, time diversity is not a good solution to correct the multipath problem since implementing time diversity in the DCT would require at least twice as much time to be allotted to each channel.
15 Similarly, frequency diversity is problematic for a TDD system in that both base stations and portable handheld units are designed to operate at only one frequency. Therefore, to combat this fading, the base station might include two or more antennas. Each antenna receives a different standing
20 wave pattern. The base station attempts to select the antenna with the stronger signal path. This technique is referred to as space diversity. Some typical signal levels versus location plots are shown in Figure 2. As long as the portable unit moves a small percentage of the fading distance
25 in a frame time (equivalent to a burst), the ideal signal path will be the same for both base station and the portable unit within one frame or burst time.

It is possible to build two entire receive chains (i.e., hardware and software required to detect, demodulate
30 and decode the received signal) in the base station radio, and after each burst is received use data from the burst with the higher signal strength or the lowest error rate. This technique, often called selection diversity, works very well. Although, selection diversity may be very effective in
35 combatting the effects of fading, it has several drawbacks.

First, providing a separate receive chain for each of the antennas drives up the cost and complexity of the

system. If it is desirable to provide a low cost processor
to provide the switching control, a separate receive chain
for each antenna may be prohibitive. Furthermore, the added
complexity in evaluating the signal as received and
5   demodulated by each receive chain adds to the cost of the
processor and requires more complicated·programming.

     Alternatively, multiple antennas may be used with a
single receive chain. However, these diversity systems
although less expensive and less complex to implement, create
10 other design problems. For instance, almost all radio
receivers implement some form of gain control to prevent
saturation and degradation due to intermodulation when the
received signal level is too high or to increase the signal-
to-noise ratio of the received signal when the received
15 signal level is too low. ·Since the signal level received by
each antenna may vary, the gain required for each antenna may
also vary. In the past, determining the proper gain
adjustment for a selected antenna could only begin after the
antenna was actually switched to an ON state. Therefore, it
20 has been virtually impossible to effectively combine antenna
switching and gain control in a single receive chain
implementation.

     Furthermore, previous antenna diversity systems
having a single receive chain have used an averaging
25 technique to estimate the signal levels at the OFF antennas.
Such averaging techniques require that estimates for a number
of previous frames be stored in memory. For instance if N is
the number of frames to average over, the estimated average
signal level y[n] would be:
30       $y[n] = y[n-1] + 1/N*x[n] + 1/N*x[n-N]$
where x[n] is the measured signal level of the received
signal. It is evident from the above equation that N
measured signal levels must be stored to carry out the
averaging. As N increases, so does the memory requirements
35 and the implementation costs.

     Another disadvantage of switch diversity using a
single receive chain is that when a signal on one antenna is

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weak but usable, the signal on the other antenna may be
weaker. In that event it would be undesirable to switch to
the other antenna merely to determine that the received
signal from that antenna is not only weak is just as poor or
5 even, but unusable. Some previous diversity systems have
provided some control to enable or disable switching if the
received signal is determined to be acceptable. However,
such systems have merely considered the signal level of the
received signal in determining whether the received signal
10 using the currently selected antenna is acceptable.
Typically, other characteristics of the received signal
should be considered to avoid unnecessary and ineffective
switching.

        Therefore, there is a need for a method providing
15 antenna diversity and gain control in a single chain
implementation which is both low in cost and simple to
implement without substantially reducing the performance of
the communications.

Summary of the Invention

20   The present invention fulfills this need by
providing simple, low cost, methods for combining both
antenna diversity and gain control in a single chain
implementation. In particular one method according to the
present invention uses a variety of input parameters which
25 characterize the quality of the received signal to generate a
signal quality indicator. The signal quality indicator is
used to enable or disable an antenna diversity procedure and
a gain control procedure. In a preferred embodiment the
input parameters include an estimated frequency variance of
30 the received signal, an estimated timing variance of the
received signal, an estimated average signal strength of the
received signal, and an estimated frame error rate of the
received signal. In a more preferred embodiment, the
frequency variance, timing variance, average signal strength
35 and frame error rate are estimated using an infinite impulse
response (IIR) digital filter thereby eliminating the need to
store many previous estimates in memory.

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The present invention also provides a method of selecting one of two antennas in a single chain diversity system. According to this method of the present invention, a first antenna is selected to receive a transmitted signal.
5   The selected antenna then receives the antenna diversity transmitted signal. A received signal strength indicator (RSSI) is input to the procedure and an average signal level for a number of bursts is estimated based in part on the RSSI. The signal level at the second antenna is then
10 estimated based on the estimated average signal level and a previous estimated signal level at the second antenna. The RSSI and the estimated signal level at the second antenna are compared to provide an antenna diversity indicator which indicates which of the two antennas should be selected on the
15 next burst. One of the two antenna is then selected based on the antenna diversity indicator. In a preferred embodiment the estimated average signal level and the estimated signal level at the second antenna are generated using appropriate IIR filters.
20   The present invention also provides a method of controlling the gain in a single chain diversity communications system. According to a preferred embodiment, one of three gain paths is provided by the communications system. The first gain path has the highest gain, the second
25 gain path provides a medium gain, and the third gain path will provides the lowest gain. One of the gain paths is selected. The transmitted signal is received and amplified by the gain corresponding to the selected gain path. The amplified signal level is measured to provide a current
30 signal level. A low gain accumulator and a high gain accumulator are updated based on the current signal level.
    A gain path with a lower gain is selected if one exists and if the low gain accumulator exceeds a predetermined switching threshold. A gain path with a higher
35 gain is selected, if one exists and if the high gain accumulator exceeds the predetermined switching threshold. In a preferred embodiment, a high threshold and a low

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threshold are defined. The step of updating the gain accumulators is preferably carried out differently depending upon whether the current signal level falls above the high threshold, below the low threshold, or in between the two

5   thresholds. Updating the gain accumulators is preferably carried out using an IIR filter.

Brief Description of the Drawings

The present invention will be better understood, and its numerous objects and advantages will become apparent

10   by reference to the following detailed description of the invention when taken in conjunction with the following drawings, in which:

Figure 1 is a timing diagram of a DCT system using TDD;

15   Figure 2 shows signal fading as a function of distance;

Figure 3 is a block diagram of the base station receiver architecture;

Figure 4 is a flow diagram of the combined antenna

20   diversity procedure and gain control procedure as carried out by the processor of the present invention;

Figure 5 is a detailed flow diagram of the input parameter selection step shown generally in Figure 4.

Figure 6 is a detailed flow diagram of the signal

25   quality update step shown generally in Figure 4.

Figure 7 is a detailed flow diagram of the control function step shown generally in Figure 4.

Figure 8 is a detailed flow diagram of the antenna diversity procedure according to a preferred embodiment of

30   the present invention; and

Figure 9 is a detailed flow diagram of the gain control procedure according to a preferred embodiment of the present invention.

Detailed Description

35   The base station receiver structure is shown in Figure 3. A first antenna 10 and a second antenna 12 are shown coupled to switch 14. Switch 14 couples either the

first antenna 10 or the second antenna 12 to the receiver
electronics depending upon the diversity control indicator 29
which is an input to switch 14. A signal transmitted from a
portable handset is received by the selected antenna and
5 passed to the gain control switch 18 by switch 14. Depending
upon the gain control indicator 28, the gain control switch
18 selects one of three gain paths 15, 19 or 17. In
particular switch 16 is configured to receive the gain
control indicator 28 and select either the gain path 15, the
10 no gain path 19, or the attenuation path 17. In a preferred
embodiment, the gain path 15 is implemented using an 18 dB
low noise amplifier and the attenuation path 17 is
implemented using a 20 dB attenuator.

The received signal output from the gain control
15 switch 18 is then input to a radio frequency integrated
circuit (RFIC) 20 wherein the received signal is
downconverted, filtered and amplified as is typical in a RF
receiver. Similarly, the received signal is further
downconverted, filtered and amplified in the intermediate
20 frequency integrated circuit (IFIC) 22. The IFIC 22 also
provides a power measurement device 21 which detects the
power level of the received signal in the IFIC 22 to provide
a Receive Signal Strength Indicator (RSSI) 27. If a gain
adjustment has been made by the gain control switch 18, the
25 value of the RSSI will reflect that adjustment such that the
output 27 is RSSI plus a gain value. The received signal
output from the IFIC 22 is shown as interface 23 and is
provided as an input to the receiver 26. In a preferred
embodiment the receiver 26 will provide a demodulator such as
30 the one described in co-pending application serial no.
07/999,210. The receiver 26 demodulates the received signal
to regenerate the transmitted data and output the data 32 to
processor 25. During the demodulation process, receiver 26
determines the frequency variance (Fvar) of the received
35 signal and outputs Fvar over interface 30 to the processor
25. Similarly, a timing variance (Tvar) related to symbol
jitter is determined by receiver 26 during the demodulation

process. Receiver 26 outputs Tvar to the processor 25 over interface 31.

The processor 25 implements a gain control procedure which uses the data, Fvar, Tvar, and the RSSI to
5 determine which of the three gain paths 15, 19, or 17 should be selected on the next burst by switch 18. The output of the gain control procedure is the gain control indicator 28 shown in Figure 3. Similarly, processor 25 implements an antenna diversity procedure which utilizes the data, Fvar,
10 Tvar, and RSSI inputs to generate the diversity control indicator 29.

A flow diagram of the overall antenna diversity and gain control procedures carried out by processor 25 is shown in Figure 4. The processor checks the data interface with the
15 receiver for an input of data following each burst as shown at 100. All of the inputs utilized by the procedures are obtained at 102 either directly from the other inputs to the processor, i.e., the RSSI, the Fvar, and Tvar inputs, or generated by the processor's software from one or more of
20 these inputs. The inputs are filtered through an IIR filter at 104 to generate a substantially average value for each of the input parameters. A signal quality indicator (SQI) is updated at 106. The signal quality indicator is based upon the value of each of the filtered inputs and a desired Bit
25 Error Rate (BER). A control program enables or disables the gain control procedure and the antenna diversity procedure at 107 depending upon the SQI. The antenna diversity procedure and the gain control procedure are executed at 108 and 110, respectively. Both procedures are executed even if they have
30 been disabled. Details of each of the steps 102 through 110 are provided below.

The output of the antenna diversity procedure is the diversity control indicator discussed in connection with Figure 3. If the antenna diversity procedure is disabled the
35 diversity control indicator will remain the same for each burst that it is disabled. The processor, then waits for the beginning of the next transmit slot at 112 and then outputs

the diversity control indicator causing switch 14 in Figure 3
to switch between the first and second antennas under the
control of the diversity control indicator as shown at 114.
Then when the base station transmits back to the portable
5 handset it will transmit on the best of the two antennas in
terms of signal quality and performance. Moreover, if the
antenna diversity procedure is disabled then switch 14 will
not switch between the first and second antennas because
consecutive diversity control indicators will be the same
10 while the antenna diversity procedure is disabled.
Similarly, the gain control indicator is used to select one
of the three gain paths as shown at 120 just before the next
receive slot as shown at 116. The process then begins over
again by checking the interface with the receiver for a data
15 input.
        Figure 5 is a detailed flow diagram of the
procedure used to collect the processor inputs shown as step
102 in Figure 4. The processor checks the receiver data
interface at 100 and determines whether or not data is
20 present on the interface at 130. If the data is present
following a burst, the processor reads the RSSI, Fvar, and
Tvar inputs at 138. Since the transmitted signal contains a
CRC field as shown in Figure 1, the processor can then
execute a conventional CRC to determine whether the data is
25 valid at 140. If it is not, then a frame indicator (FI) is
set to "POOR" at 142. If the CRC shows that the data is
valid at 140, then the FI is set to "GOOD" at 144.
        If no data is received by the processor at the end
of a burst as determined at 130, the processor reads the RSSI
30 input at 132. The Fvar and Tvar inputs generally are not
generated when data is not available, so these inputs are set
to constants K1 and K2, respectively at 134. Furthermore, if
no data was received, the entire frame or burst is considered
to be a MISS or a FAILURE. Therefore, the FI is set to MISS
35 at 156. Thus the inputs provided to step 104 include the
RSSI, Fvar, Tvar. and a FI.

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The present invention preferably utilizes a signal quality estimator to determine whether the received signal quality is good or poor. The signal quality estimator according to the present invention accepts an input of the
5 following parameters:

        $F'var[n]$ the estimated frequency variance for the current frame;

        $T'var[n]$ the estimated timing variance for the current frame;

10        $SA[n]$ the estimated average signal strength for the current frame; and

        $F[n]$ the estimated frame error rate for the current frame;

where n corresponds to a frame in time, i.e. digital time.
15   The estimated frequency variance, time variance, and average signal strength are derived from filtering the input parameters Fvar, Tvar, and RSSI, respectively. In a preferred embodiment, a simple first order IIR filter is used as follows:

20           $F'var[n] = a*Fvar + (1-a)*F'var[n-1]$

           $T'var[n] = a*Tvar + (1-a)*T'var[n-1]$

           $SA[n] = a*RSSI + (1-a)*SA[n-1].$

where **a** is the filter gain. It should be understood that **a** may be any number between zero and one ($0<a<1$) but that the
25 selection of a determines the filter's reaction time, i.e., the time it takes to reach the steady state, and the filter's stability in the steady state, i.e., how much the response oscillates about the steady state value. In a preferred embodiment, a=1/16 has been selected to provide a relatively
30 fast filter.

        The estimated frame error rate F[n] is also derived by filtering the input parameter, however this input parameter, the frame indicator (FI), is a discrete value. As such, FI in a preferred embodiment, is set to zero if data is
35 received and has a GOOD CRC as shown in Figure 5 at 144. In that case:

           $F[n] = (1-a)*F[n-1].$

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However, if the frame indicator was set to a "MISS" at 136 or
"POOR" at 142 in Figure 5, FI is equal to one and an impulse
X is added to the IIR filter equation, such that:

$$F[n] = a*FI*X + (1-a)*F[n-1].$$

5   It should be understood that appropriate values of X and FI
are determined experimentally.

In a more preferred embodiment, it is desirable to
limit the maximum value of F[n] so that in the event that
numerous frames in a row are missed or are determined to be
10 poor, it will not take too long to recover when the data is
again received. Therefore, F[n] is preferably compared to a
predetermined maximum frame error rate M, after each burst.
If F[n] is greater than M, F[n] is set equal to M. By
limiting the maximum value of F[n] in this way, the signal
15 quality indicator can quickly change from poor to good when
the signal reception does in fact change from poor to good as
will be evident from the discussion of the signal quality
estimation procedure below.

The use of a simple IIR filter to generate the
20 estimates is advantageous in two respects. It reduces the
memory requirements in that only the most previous estimate
must be saved. It also generates these estimates quickly in
a manner simple to implement in a control processor. In
particular, where a is selected as an inverse power of 2, bit
25 shifting can be used instead of multiplication. The
computations are thus possible using 8-bit arithmetic with no
carries or fractions, providing great savings in cost without
any significant degradation in performance.

A detailed flow diagram of the Signal Quality
30 Estimation Procedure is shown in Figure 6. Each of the
estimates are compared to a predetermined threshold. If any
of the estimates except for the RSSI are greater than its
corresponding threshold, then the signal quality indicator
(SQI) is set to "POOR" at 160. If each of the estimates is
35 less than its corresponding threshold, then the SQI is set to
"GOOD" at 158.

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        Specifically, the estimated frequency variance is
compared to a frequency variance threshold (FVThresh) at 150,
the estimated timing variance is compared to a timing
variance threshold (TVThresh) at 152, the estimated frame
5   error rate is compared to a Frame error rate threshold
(FThresh) at 154, and the estimated average signal strength
is compared to an average received signal strength threshold
(RSThresh) at 156. Each of the thresholds are derived based
on a desired bit error rate for the channel. The threshold
10 values are chosen so that with the expected noise and
interference each test will fail and the signal quality will
be judged "POOR" when the data bit error rate is high enough
to cause noticeable degradation in system performance. These
thresholds are best determined by experimentation with the
15 actual system. In the preferred embodiment the thresholds
are set so the tests fail and system quality is judged
"POOR" when the bit error rate is worse than one part in
100,000.
        Figure 7 is a detailed flow diagram of the control
20 program. The control program receives the SQI as an input.
If the SQI is "GOOD" as determined at 170, the antenna
diversity procedure is disabled at 172. Then the RSSI is
checked to determine whether the received signal is strong at
174. This may be implemented by comparing the RSSI to a
25 predetermined maximum signal strength (RSmax). If the RSSI
is less than RSmax, then gain control procedure is disabled
at 176. If the RSSI is greater than or equal to RSmax, then
the gain control procedure is enabled at 182. If the SQI is
"POOR" as determined at 170, both the antenna diversity
30 procedure and the gain control procedure are enabled at 178
and 180, respectively.
        Next the antenna diversity procedure is executed
regardless of whether the control program enabled or disabled
the procedure. However, if the procedure is disabled the
35 antenna selection will not change. A detailed flow diagram
of the antenna diversity procedure is shown in Figure 8. The
estimated average signal strength is generated at 200. This

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may be the average signal strength SA[n] generated during the
step of updating the IIR filters 104 shown in Figure 4 and
described above. Alternatively, the estimated average signal
strength may be regenerated using a slower IIR filter so that
5   unnecessary switching can be avoided.

        If the first antenna is currently selected as
determined at 201, the estimated received signal level into
the first antenna (L1[n]) is set equal to the RSSI at 208.
The estimated received signal level into the second antenna
10 L2[n] is derived from a previous estimate L2[n-1] and a long
term estimate SA[n] as shown by the equation at 209. Thus
even when the antenna is in an OFF state the received signal
level can be estimated.

        If the estimated received signal level into the
15 second antenna plus a predetermined antenna selection
threshold (t) is greater than the estimated received signal
level into the first antenna as determined at 210, then the
procedure checks whether antenna diversity has been enabled
at 211. If antenna diversity has been disabled or if the
20 estimated received signal level into the first antenna is
greater than the estimated level into the second antenna plus
the threshold (t), then the antenna selection remains
unchanged and the procedure provides an output indicating
selection of the first antenna at 213. Otherwise, the
25 procedure provides an output indicating selection of the
second antenna at 212 causing a switch over from the first
antenna to the second antenna.

        Similarly, if the second antenna is selected as
determined at 201, the estimated received signal level into
30 the second antenna (L2[n]) is set equal to the RSSI plus the
selected gain at 202. The estimated received signal level
into the first antenna L1[n] is derived from a previous
estimate L1[n-1] and a long term estimate SA[n] as shown by
the equation at 203.
35   If the estimated received signal level into the
first antenna plus the predetermined antenna selection
threshold (t) is greater than the estimated received signal

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level into the second antenna as determined at 204, then the
procedure checks whether antenna diversity has been enabled
at 205. If antenna diversity has been disabled or if the
estimated received signal level into the second antenna is
5   greater than the estimated level into the first antenna plus
the threshold (t), then the antenna selection remains
unchanged and the procedure provides an output indicating
selection of the second antenna at 207. Otherwise, the
procedure provides an output indicating selection of the
10   first antenna at 206 causing a switch over from the second
antenna to the first antenna.

        The gain control procedure is provided to keep the
gain high enough to minimize the BER and low enough to
prevent saturation and degradation due to intermodulation.
15   As described above with reference to Figure 3, the handset
provides three discrete gain paths 15, 19, and 17. The
selection of one of a relatively small number of possible
gain or attenuation values is preferable in a system in which
the receiver limits and samples the received signal prior to
20   demodulation, as described in co-pending application serial
no. 07/999,210, in contrast to other receivers using an A/D
converter to digitize the receive signal. It should be
understood that when using an A/D converter, the received
signal resolution must be very good, whereas the resolution
25   is much less critical when digitizing the received signal
using a limiter and sampler combination - the primary
requirement being that the received signal level is within a
general range.

        If the gain control procedure is enabled as
30   determined at 220, the procedure compares the RSSI plus the
selected gain with a predetermined high level threshold (TH)
at 222. If the RSSI plus the selected gain is greater than
TH, then the value of a first gain accumulator $G1[n]$ is
calculated according to the equation shown at step 227, where
35   a is the IIR filter gain and X is an added impulse. Then a
second gain accumulator $G2[n]$ is updated according to the
equation shown at 228. If $G1[n]$ is greater than a gain

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switching threshold (TS), the accumulators G1[n] and G2[n]
are reset at 231. If the currently selected gain path as
determined at 237 is not the minimum, e.g. gain path 17 shown
in Figure 3, then the next lowest gain path is selected at
5 232. For instance, if the currently selected gain path is
gain path 15 having an 18 dB gain, then the next lowest gain
path is gain path 19 having no gain at all. However, if the
gain path is already the minimum gain path as determined at
step 237, no change is made to the current gain control
10 indicator as shown at 238.

        If the first gain accumulator is not greater than
the gain switching threshold at 230, then the procedure
determines whether the second gain accumulator is greater
than the gain switching threshold at 234. If it is greater,
15 the gain accumulators are reset at 235. If the currently
selected gain path as determined at 241 is not the maximum
gain path, then the gain path is increased at 239, i.e. gain
path 17 which attenuates the received signal by 20 dB is
changed to gain path 19 which does not attenuate the received
20 signal.

        As discussed above, it is desirable to simply keep
the level of the signal between a maximum and minimum range,
between a high threshold (TH) and a low threshold (TL). Thus
when the RSSI plus the selected gain is greater than TH as
25 determined at 222, the value of G1[n] is increased by adding
the impulse X as shown at 227, whereas the value of G2[n] is
permitted to decay in accordance with the IIR filtering.
However if the RSSI plus the selected gain is less than TL,
it is desirable to allow the value of G1[n] to decay in
30 accordance with the IIR filter response as shown by the
equation at 226 and the value of G2[n] is increased by the
addition of impulse X as shown at 229. Accordingly, if TL <
RSSI + selected gain < TH, no switching is necessary so both
gain accumulators are permitted to decay with the IIR filter
35 response as shown by the equations in steps 224 and 225.
Allowing the gain accumulators to decay ensures that neither

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one will exceed the gain switching threshold and therefore, the gain path will not be unnecessarily switched.

When the gain control procedure is disabled as determined at step 230, both gain accumulators are reset as
5 shown at 221. Therefore, no switching will be effected when the gain control procedure is disabled since TS is greater than the reset values.

The following describes the operating parameters of the present invention according to a preferred embodiment.
10 However, it should be understood that the following description is to be used for explanatory purposes only and is not meant to limit the invention as described hereinabove.

As a practical matter, the IIR estimation filters are initialized to constants. The accumulators are set to
15 zero during an initialization process. The initial indicators are preferably set so that the SQI will be set to "POOR".

Referring back to Figure 3, the procedures are preferably implemented in a custom processor in the BBIC 24.
20 The procedures are appropriate for many commercially available microprocessors and microcontrollers, such as the Intel 8051, the Motorola 6800, the Hitachi H8, and many others. In particular the procedures were designed to minimize RAM and ROM usage, since the processor 25, RAM (not
25 shown), and ROM (not shown) are all preferably included in the BBIC 24 digital ASIC which limits available memory resources.

The receive signal strength is preferably computed from a 5-bit (value of 0 to 31) receive signal strength
30 indicator (RSSI) read in the IFIC 22 and computed by the level measurement device 21. The indicator limits at a value of 0 and saturates at a value of 31. In this preferred embodiment, there are three possible receive gain levels, as controlled by the gain control procedure described above.
35 The signal strength is estimated from the following parameters and equation:

n: digital "time" measured in bursts

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> G[n]: gain of receiver at frame n; G[n] will be
> high, middle, or low
> f(): signal strength offset function
> RSSI[n]: receive signal strength indicator at frame n
> a: RSSI indicator slope
> SS[n]: signal strength indicator at slope n
>
> $$SS[n] = a*RSSI[n] + f(G[n])$$

In this preferred embodiment a is about 1.25 dB/(RSSI step)
and f(high gain) is about -109 dBm, f(middle gain) is about -
93 dBm, and f(low gain) is about - 69 dBm. Although these
values are preferred in a DCT system operating as described
above, the antenna diversity procedure and gain control
procedure are operational with most signal strength
indicators.

        For the antenna diversity algorithm described in
conjunction with Figure 8, a, the signal strength filter
constant, is preferably set to 1/64 and is implemented as a
shift right 6 times, b, the diversity IIR filter gain, is
preferably set to 1/16 and is implemented as a shift right 4
times, and t, the antenna switching threshold, is about 1.25
dB (or equivalent to one RSSI step in this preferred
embodiment).

        In addition to the current signal level information
described above, the parameters used in this gain control
procedure are:

> THigh, the high level threshold, which is a
> function of the selected gain level:
>> high gain: = -80 dBm
>> medium gain: = -60 dBm
>> low gain: = 0 dBm
>
> TLow, the low level threshold, which is a function
> of the current gain level:
>> high gain: -106 dBm
>> medium gain: -82 dBm
>> low gain: -62 dBm
>
> Ts, the switching threshold, is set to 64.
>
> a, the IIR filter gain, is 1/16 or a right shift
> four times; and
> X, the input impulse, equals 32.

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Like the antenna diversity procedure, the gain control procedure would be operational for many other parameter values. As would be understood by those skilled in the art these parameter would be adjusted depending upon the communications system and its operation.

The procedure for estimating the frame error rate as described herein preferably uses the following parameters:
a, the frame error rate gain, is 1/16 or a shift right four times
M, the maximum value for frame error rate filter, equals 63
x, the impulse value, is 64

The receive signal level threshold is a function of receive gain level. Preferably the receive signal strength threshold (RSTHRESH) is 10. The other thresholds shown in Figure 6 are as follows:

FVThresh: The frequency variance threshold corresponds to an error rate of 0.00001.
TVThresh: The timing variance threshold corresponds to an error rate of 0.00001.
FThresh: The frame error rate threshold equals 31.

While the invention has been described and illustrated with reference to specific embodiments, those skilled in the art will recognize that modification and variations may be made without departing from the principles of the invention as described hereinabove and set forth in the following claims.

In the Claims:

1.   In an RF receiver having a plurality of selectable
antennas, a plurality of selectable gain paths, and a
processor for executing an antenna diversity procedure to
5 select one of said plurality of selectable antennas and for
executing a gain control procedure for selecting one of said
plurality of selectable gain paths, said receiver receiving a
signal being indicative of transmitted data, said data being
transmitted in bursts, a method of enabling and disabling
10 said antenna diversity and gain control procedures comprising
the steps of:
            accepting an input, for each burst, of at least one
of a frequency variance indicative of a phase offset of the
received signal, a timing variance indicative of symbol
15 jitter in the received signal, a received signal strength
indicative of a power level of the received signal, and a
frame error rate indicative of a number of bursts which are
not detected by the RF receiver;
            averaging each input so accepted to generate an
20 estimate of each input for a period of time corresponding to
a next burst of transmitted data;
            generating a signal quality indicator based upon
each of said inputs so averaged; and
            disabling said antenna diversity and said gain
25 control procedures based on said signal quality indicator.

2.   The method of claim 1, wherein each burst of
transmitted data includes CRC information, the method further
comprising the steps of:
            determining whether data was received by the
30 receiver during a most previous burst; and
            defining a frame indicator, if data was so
received, based on said CRC information, wherein said frame
error rate is related to said frame indicator.

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3.   The method of claim 1, wherein said antenna diversity procedure is disabled when said signal quality indicator is acceptable.

4.   The method of claim 1, wherein said gain control
5 procedure is disabled when said signal quality indicator is acceptable and when said received signal strength is greater than a predetermined signal strength threshold.

5.   The method of claim 1, wherein said signal quality indicator is acceptable if each of the following is true:
10   said frequency variance so averaged is greater than a predetermined frequency variance threshold,
            said timing variance so averaged is greater than a predetermined timing variance threshold,
            said frame error rate so averaged is greater than a
15 predetermined frame error rate threshold, and
            said received signal strength indicator so averaged is less than a predetermined signal strength threshold; and
            said antenna diversity and said gain control procedures being disabled only if said signal quality
20 indicator is acceptable.

6.   The method of claim 1, wherein the step of averaging said inputs so accepted is carried out using an infinite impulse response digital filter.

7.   A method of selecting one of two antennas to
25 optimize a bit error rate in a communications system using spacial diversity, said communications system transmitting data in bursts, comprising the steps of:
            selecting a first antenna to receive a transmitted signal;
30   receiving said transmitted signal and defining the same as a received signal;

accepting an input indicative of a level of said
transmitted signal, said input being defined as a received
signal strength indicator (RSSI);

estimating an average signal level for a number of
5 bursts;

estimating a signal level at a second antenna based
on said average signal level so estimated and a previous
estimated signal level at said second antenna;

comparing said RSSI and said estimated signal level
10 at said second antenna to provide an antenna diversity
indicator indicative of a selection of one of said two
antenna; and

selecting one of said two antenna based on said
antenna diversity indicator.

15 8.   The method of claim 7, wherein said step of
estimating said average signal level is carried out using an
infinite impulse response digital filter.

9.   The method of claim 8, wherein the average signal
level so estimated is based on at least a previous estimate
20 of said average signal level and the RSSI.

10.   The method of claim 7, wherein said step of
estimating the signal level at said second antenna is carried
out using an infinite impulse response digital filter.

11.   The method of claim 10, wherein said signal level
25 at said second antenna so estimated is based on at least a
previous estimate of said signal level at said second antenna
and said average signal level so estimated.

12.   The method of claim 7, further comprising the steps
of:
30   receiving a selection enable input indicating
whether said step of selecting one of said two antennas is
enabled; and

said selection step being carried out only if said selection indicator indicates said selection step is enabled.

13.   A method of adjusting gain control in an RF receiver, said receiver having at least three selectable gain
5 paths, a first of said gain paths providing a highest gain, a third of said gain paths providing a lowest gain, and a second of said gain paths providing a medium gain, the method comprising the steps of:
        selecting one of said three gain paths and defining
10 said gain path as a selected gain path;
        receiving a transmitted signal;
        accepting an input indicative of a level of said transmitted signal, said input being defined as a received signal strength indicator (RSSI);
15   combining the gain of said selected gain path with said RSSI to define a current signal level:
        updating a low gain accumulator and a high gain accumulator based on said current signal level;
        selecting a lower gain path, if one exists and if
20 said low gain accumulator exceeds a predetermined switching threshold; and
        selecting a higher gain path, if one exists and if said high gain accumulator exceeds said predetermined switching threshold.

25 14.   The method of claim 13, further comprising the steps of:
        defining a high threshold and a low threshold indicative of a desired range of a signal level of said received signal;
30   comparing said current signal level with said high and said low thresholds; and
        said step of updating said high and low gain accumulators being based on said comparison.

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15.   The method of claim 13, wherein the step of
updating said gain accumulators is carried out using an
infinite impulse response digital filter.

16.   The method of claim 16, further comprising the
5 steps of:
        defining a high threshold and a low threshold
indicative of a desired range of a signal level of said
received signal;
        inputting an impulse to said infinite impulse
10 response filter corresponding to said low gain accumulator if
said current signal level exceeds said high threshold; and
        inputting said impulse to said infinite impulse
response filter corresponding to said high gain accumulator
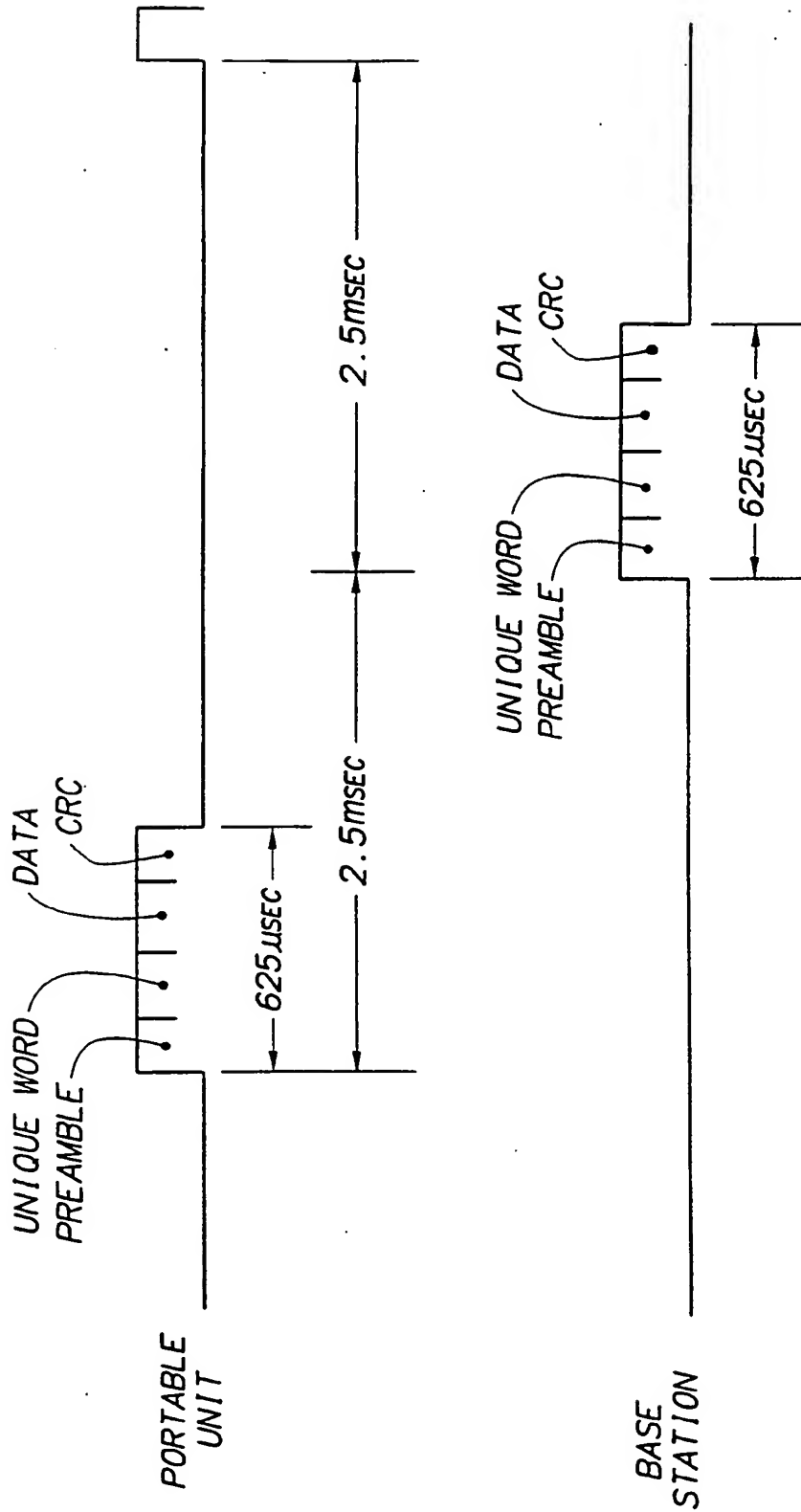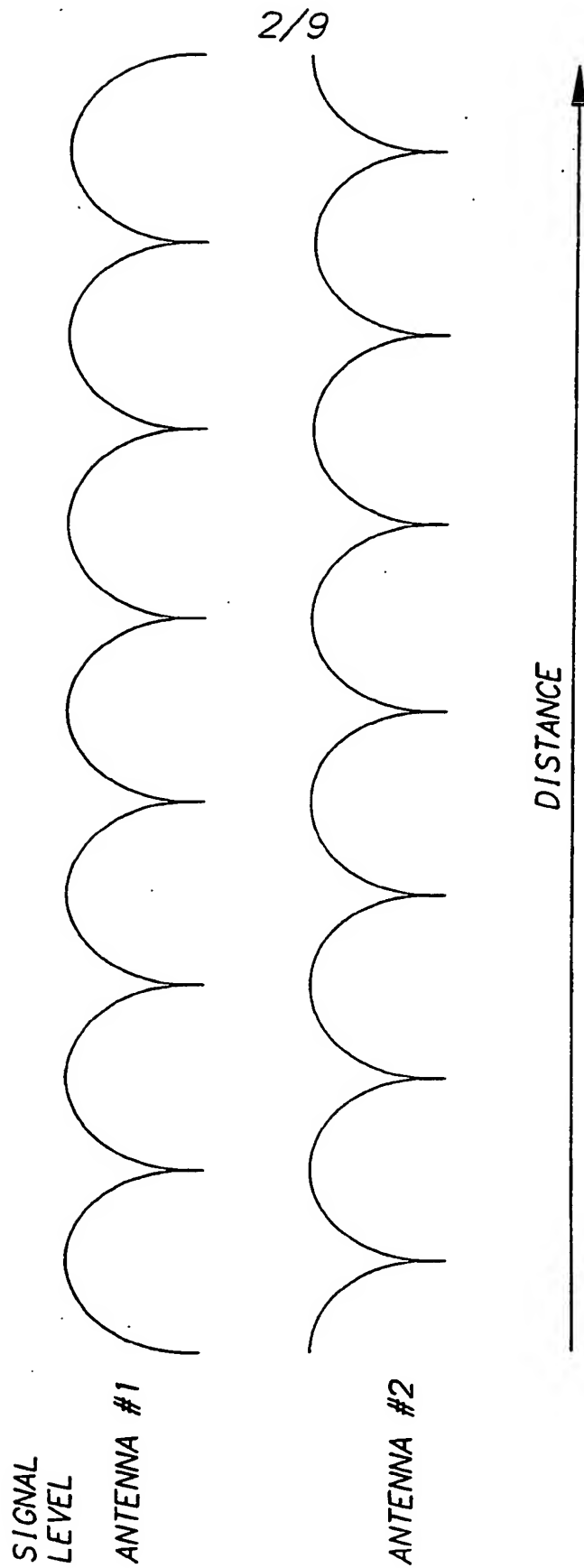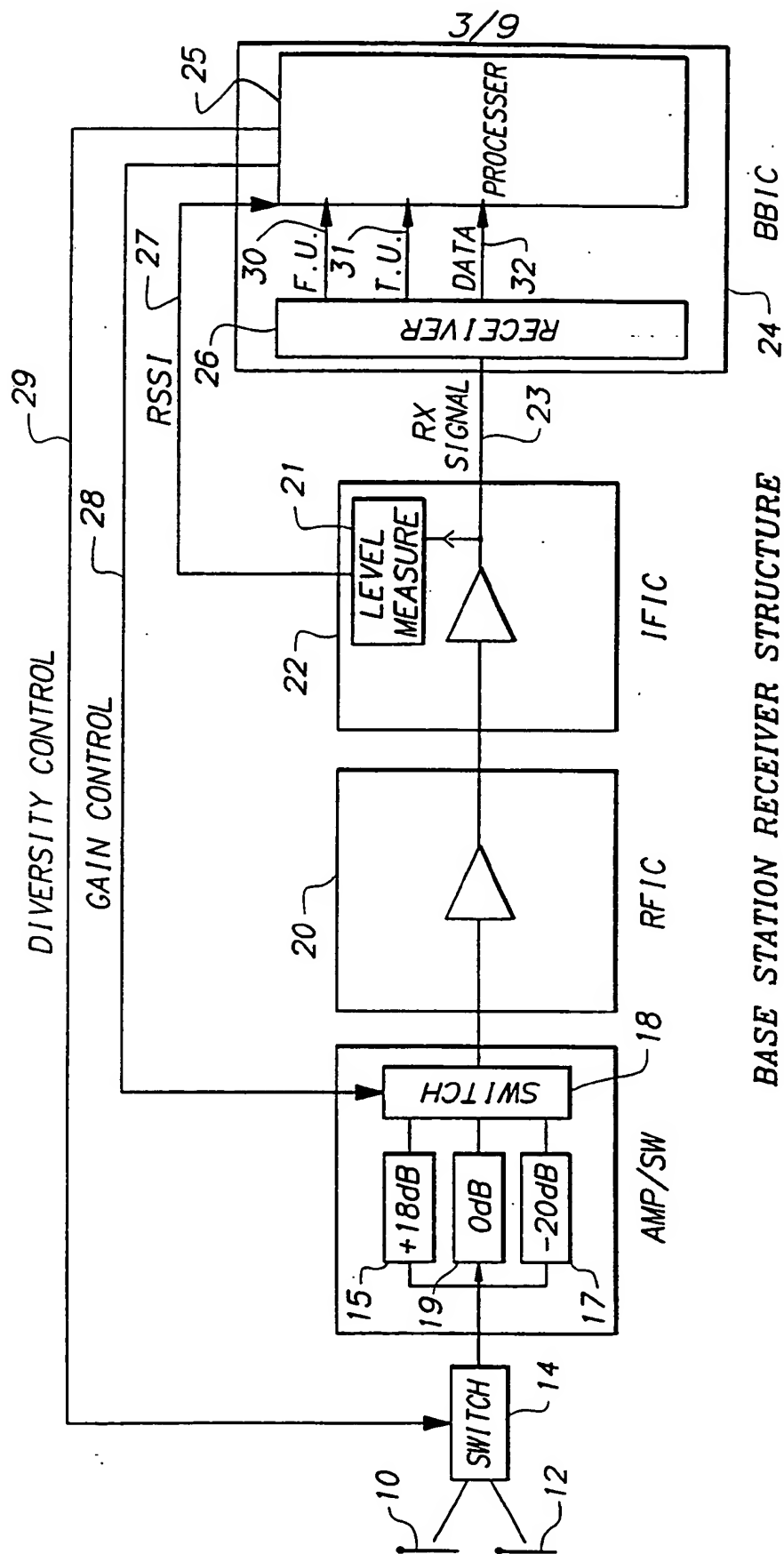if said current signal level exceeds said low threshold.

FIG. 1

PORTABLE UNIT

UNIQUE WORD
PREAMBLE
DATA
CRC

625 μsec

2.5 msec

2.5 msec

BASE STATION

UNIQUE WORD
PREAMBLE
DATA
CRC

625 μsec

SIGNAL
LEVEL
ANTENNA #1

ANTENNA #2

DISTANCE

FIG. 2

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BASE STATION RECEIVER STRUCTURE

FIG. 3

4/9

START ────────────────▶ CHECK
                         RCVR ─────────── 100

                          │
                          ▼

102 ─┐
     COLLECT
     INPUT
     PARAMETERS

                          │
                          ▼

104 ─┐
     UPDATE IIR
     FILTERS FOR
     EACH INPUT

107 ─┐   106 ─┐   │
     CONTROL   UPDATE SIGNAL
     FUNCTION ◀───── QUALITY
                     INDICATOR

                          │

108 ─┐
     PERFORM ANTENNA
     DIVERSITY
     PROCEDURE

                          │
                          ▼

110 ─┐
     PERFORM GAIN
     CONTROL
     PROCEDURE ─────────▶

120 ─┐
     SET SWITCH 18
     ACCORDING TO
     GAIN CONTROL 28

                          ▲

116 ─┐
     NEXT
     RCV   N
     SLOT
     ?

SET SWITCH 14
ACCORDING TO
DIVERSITY
CONTROL 29

114 ─┘

112 ─┐
     NEXT
     XMT   N
     SLOT
     ?
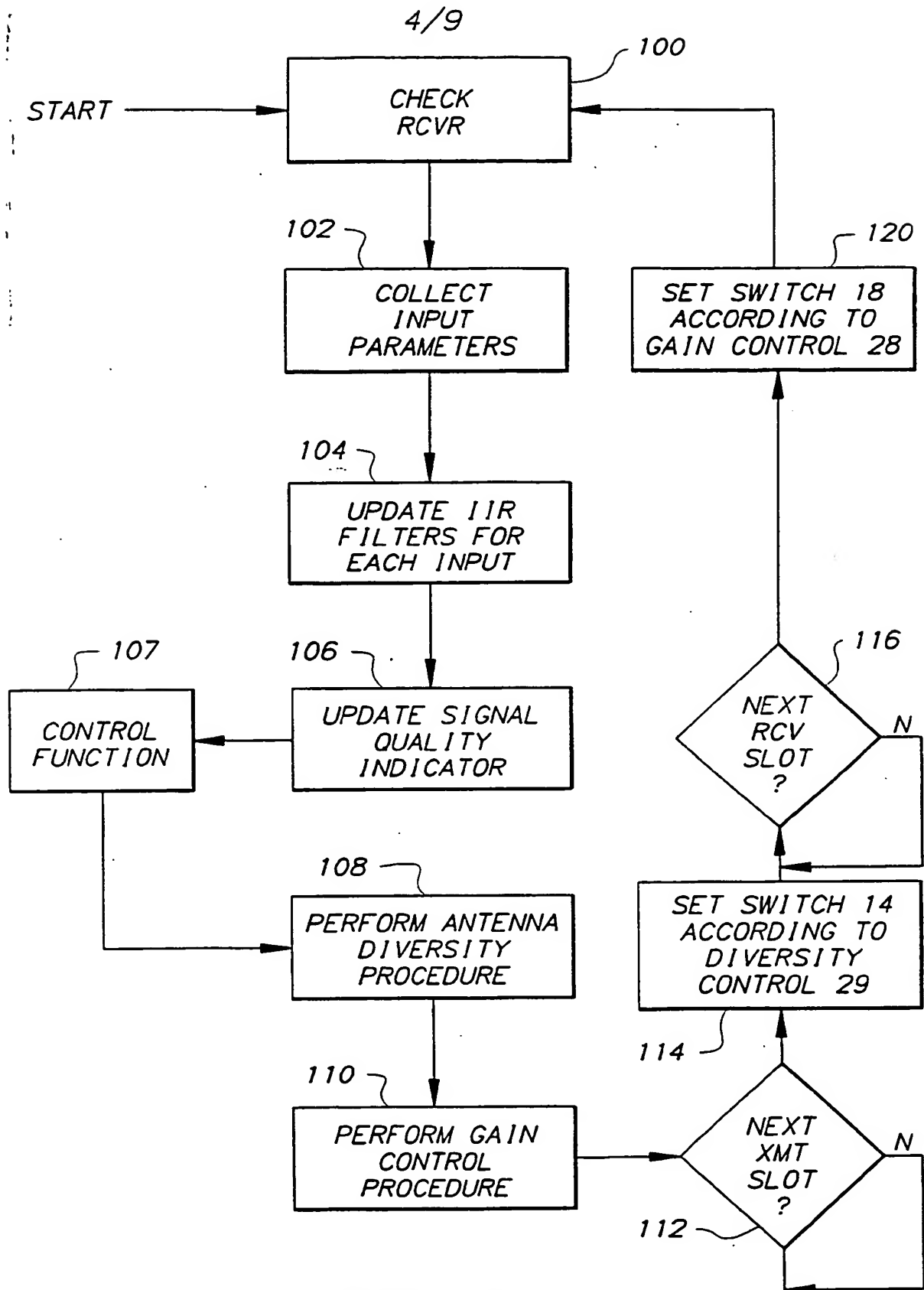
FIG. 4
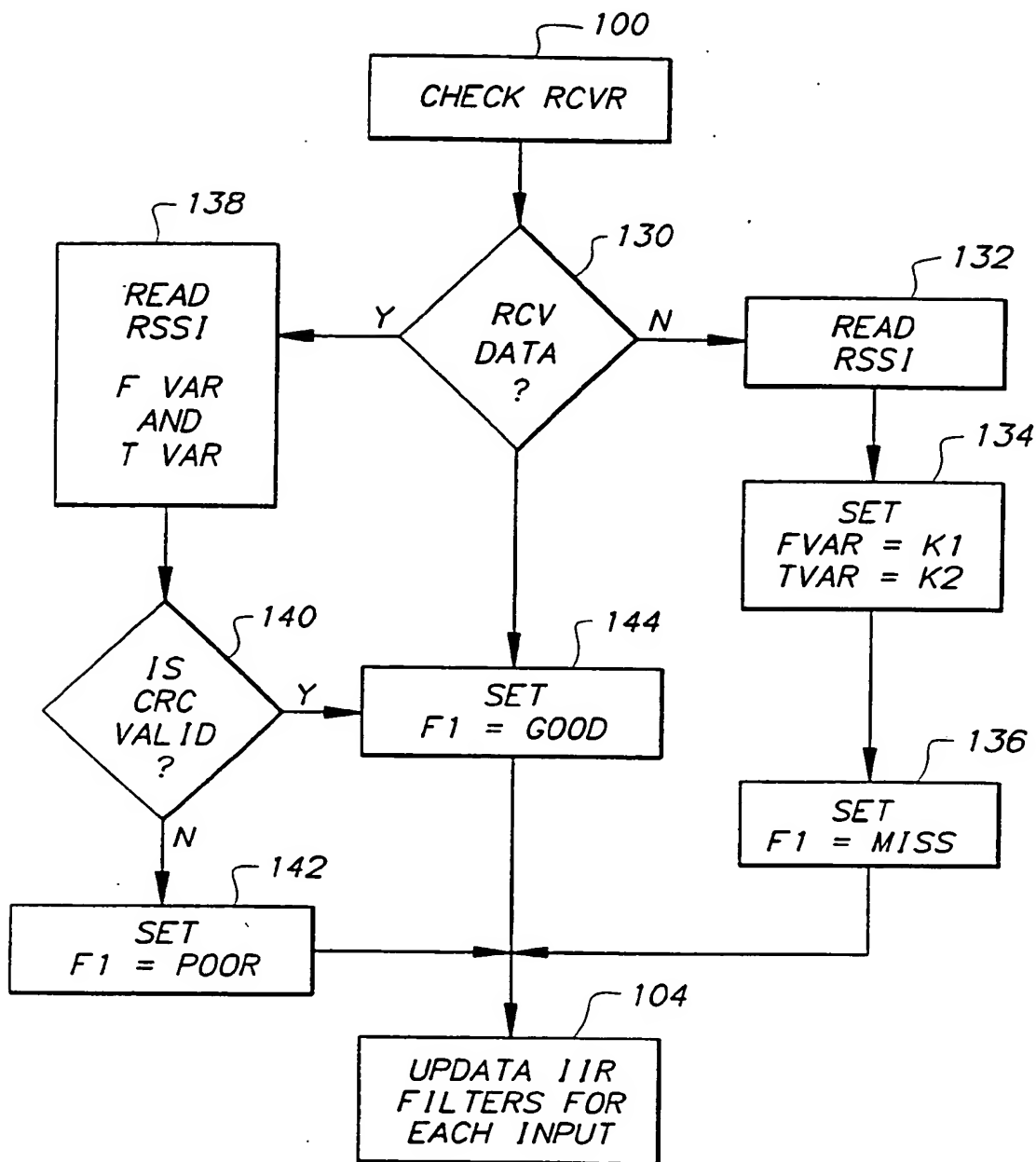
SUBSTITUTE SHEET (RULE 26)

FIG. 5
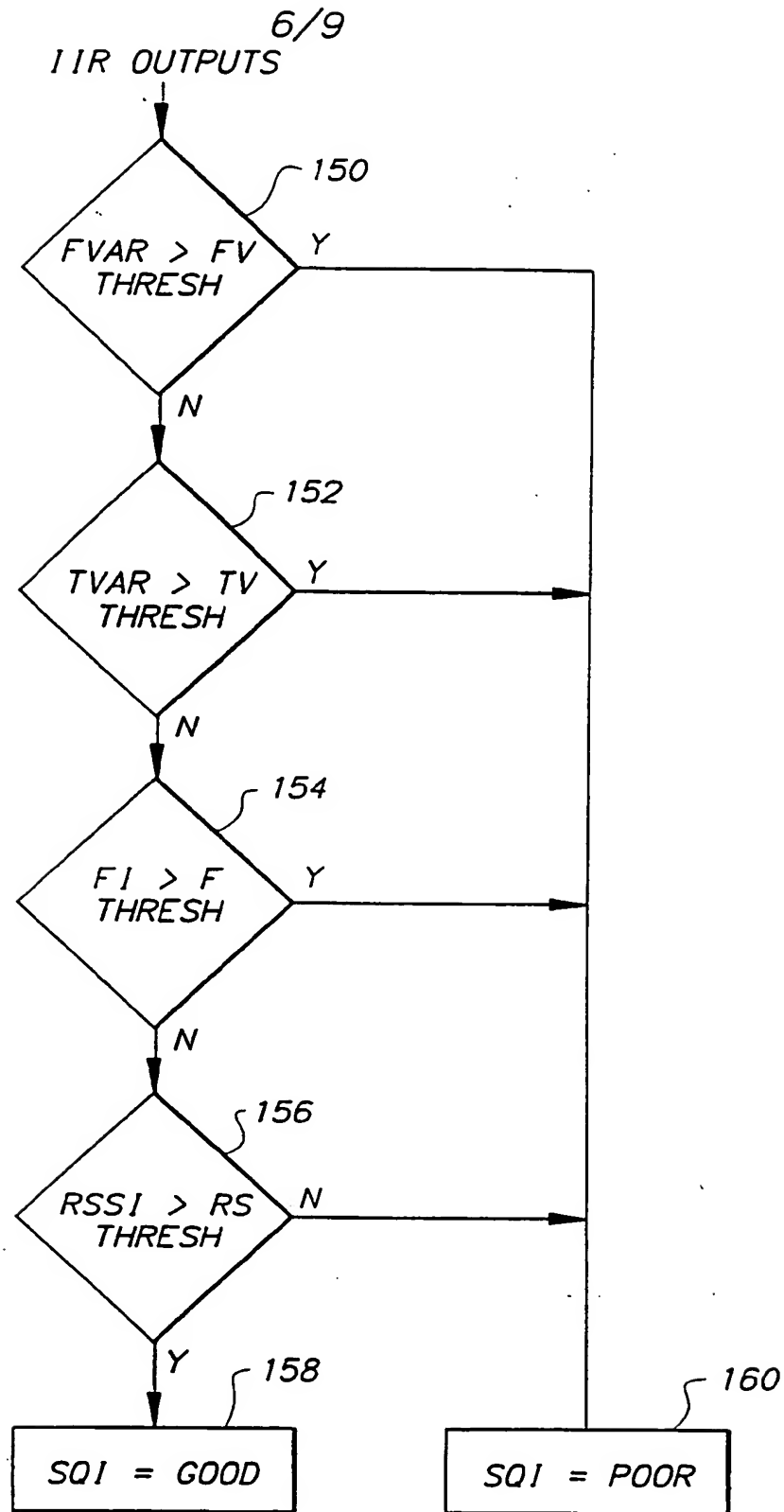
FIG. 6

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FUNCTION CONTROL
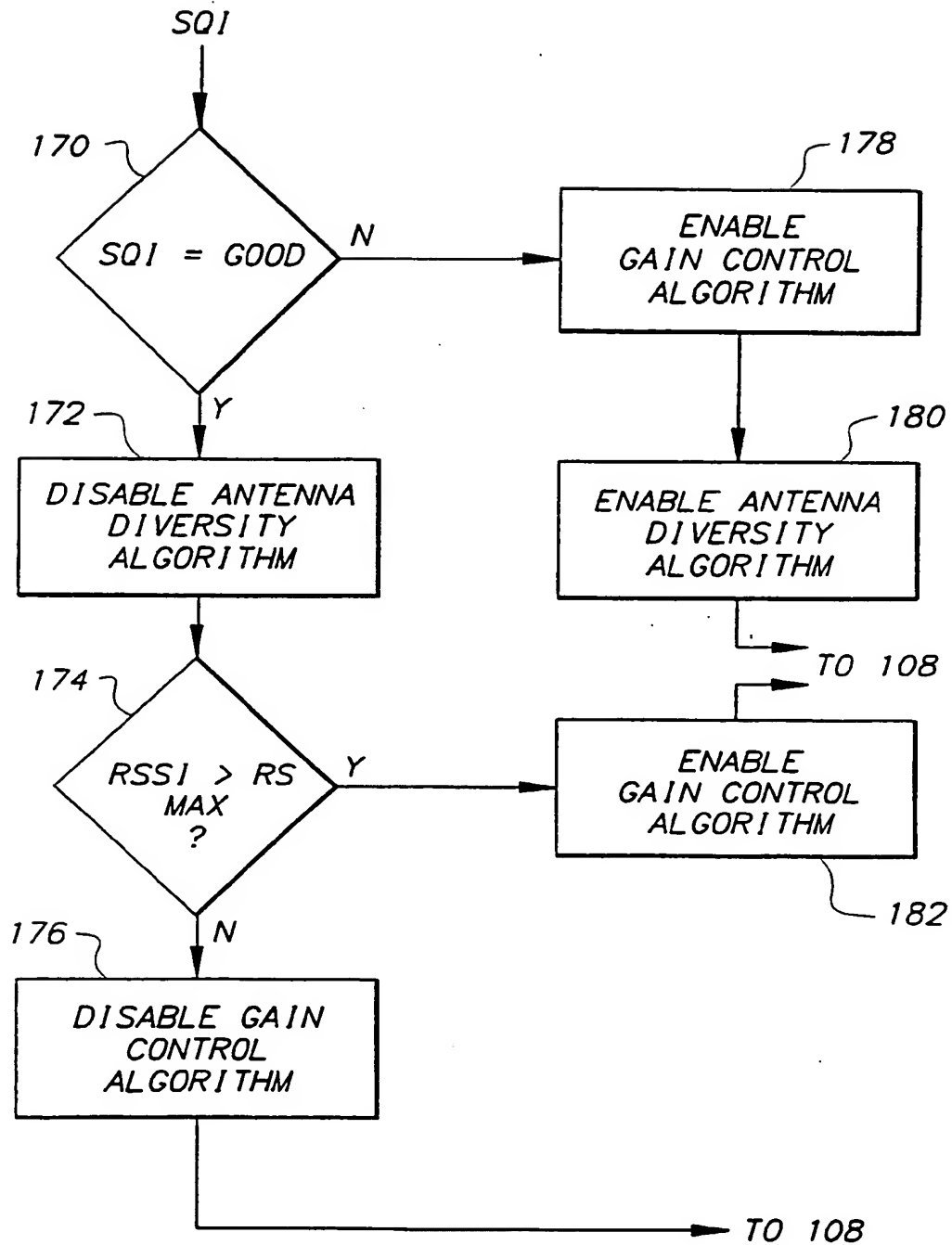
FIG. 7

SUBSTITUTE SHEET (RULE 26)
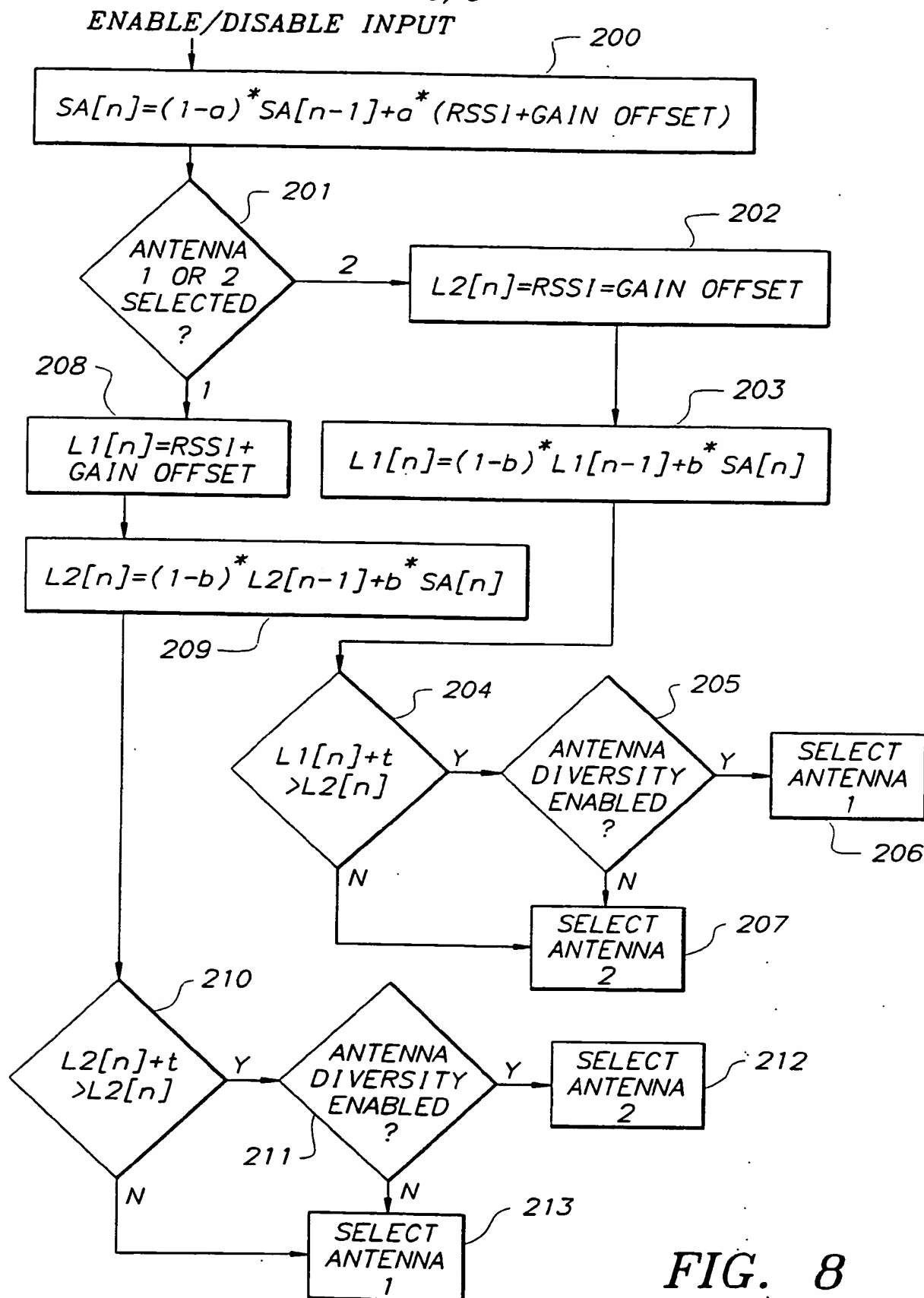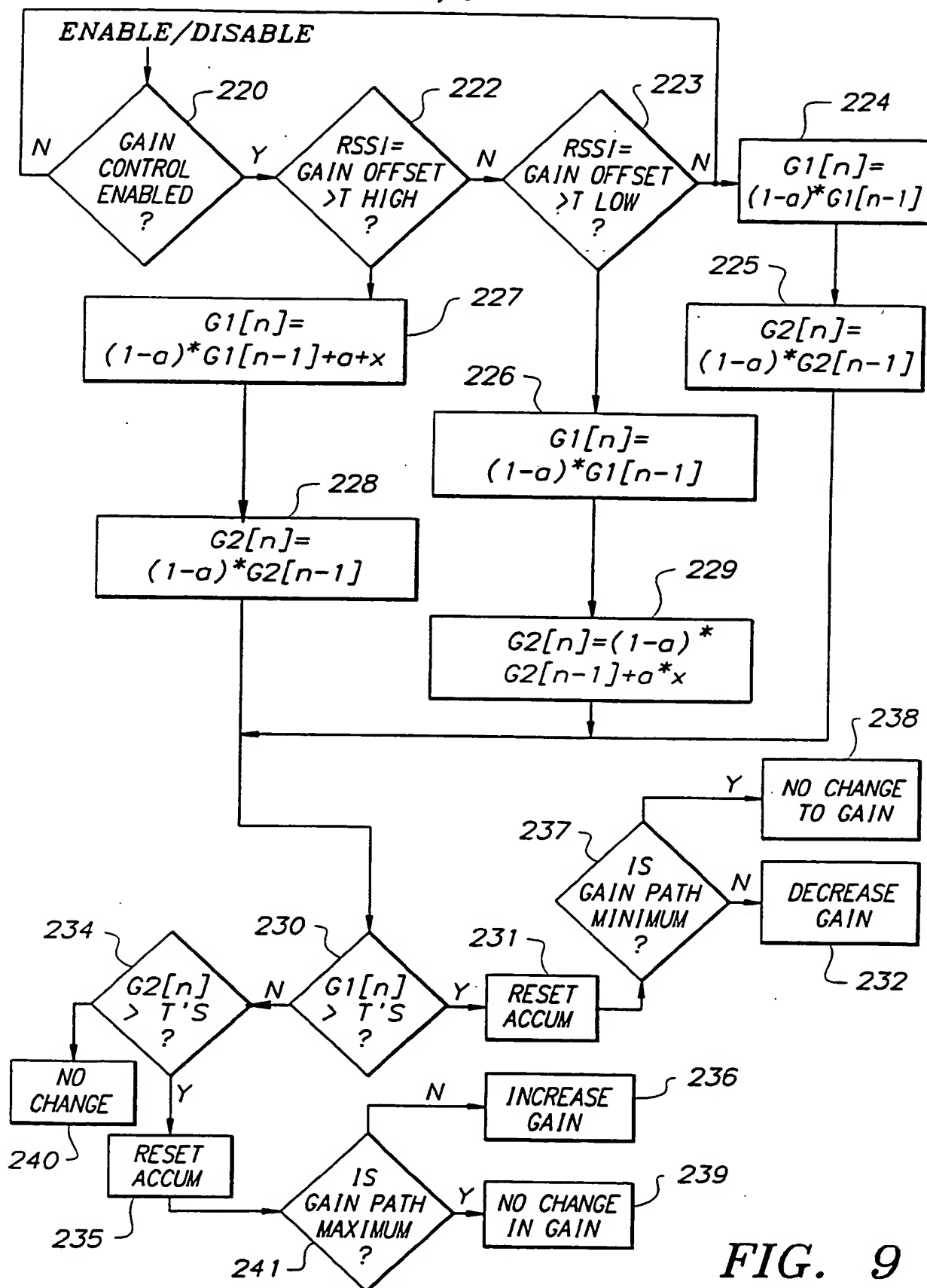
ENABLE/DISABLE INPUT

200

$$SA[n]=(1-a)^*SA[n-1]+a^*(RSSI+GAIN\ OFFSET)$$

201

ANTENNA 1 OR 2 SELECTED ?

2 → 202

$$L2[n]=RSSI=GAIN\ OFFSET$$

1

208

$$L1[n]=RSSI+GAIN\ OFFSET$$

203

$$L1[n]=(1-b)^*L1[n-1]+b^*SA[n]$$

$$L2[n]=(1-b)^*L2[n-1]+b^*SA[n]$$

209

204

$$L1[n]+t>L2[n]$$

Y → 205

ANTENNA DIVERSITY ENABLED ?

Y → SELECT ANTENNA 1

206

N

N → SELECT ANTENNA 2

207

210

$$L2[n]+t>L2[n]$$

Y → 211

ANTENNA DIVERSITY ENABLED ?

Y → SELECT ANTENNA 2

212

N

N → SELECT ANTENNA 1

213

FIG. 8

FIG. 9

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US94/11122

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :H04L 1/02; H04L 27/08

US CL :375/10, 98, 100; 455/33.3, 134-136

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 375/10, 98, 100; 455/33.3, 134-136

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

375/10, 40, 98, 100; 455/33.1, 33.3, 134-136, 138, 277.1; 379/58-62

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

USPTO APS (diversity, gain control, quality indicator)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A, P	US, A, 5,325,403 (SIWIAK et al.) 28 June 1994 (28.06.94) Fig. 1	1,7
A, P	US, A, 5,267,272 (CAI et al.) 30 November 1993 (30.11.93) Fig. 3	13
A	US, A, 5,187,809 (RICH et al.) 16 February 1993 (16.02.93) Fig. 5	13
A	US, A, 5,184,349 (RIORDAN) 02 February 1993 (02.02.93) Fig. 3	13
A	US, A, 5,119,501 (PERRY et al.) 02 June 1992 (02.06.92) Fig. 5	1,7

☐ Further documents are listed in the continuation of Box C.   ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be part of particular relevance		
"E"	earlier document published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed	"&"	document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 NOVEMBER 1994	06 FEB 1995
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	Authorized officer YOUNG T. TSE
Facsimile No. (703) 305-3230	Telephone No. (703) 305-4736

Form PCT/ISA/210 (second sheet)(July 1992)*

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US94/11122

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
   because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
   because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
   because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
   Telephone Practice
   Please See Extra Sheet.

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest   ☐ The additional search fees were accompanied by the applicant's protest.

   ☒ No protest accompanied the payment of additional search fees.

Form PCT/ISA/210 (continuation of first sheet(1))(July 1992)*

BOX II. OBSERVATIONS WHERE UNITY OF INVENTION WAS LACKING
This ISA found multiple inventions as follows:

Group I.   Claims 1-6, drawn to a method of enabling and disabling an antenna diversity procedure and a gain control procedure in an RF receiver, classified in class 375, subclass 10.

Group II.   Claims 7-12, drawn to a method of selecting one of two antenna to optimize a bit error rate in a communications system, classified in class 375, subclass 100.

Group III.   Claims 13-16, drawn to a method for adjusting gain control in an RF receiver, classified in class 375, subclass 98.

The inventions are distinct because the method claim 1 in Group I recites an antenna diversity procedure and a gain control procedure by a signal quality indicator based on the average inputs of the RF receiver. The method claim 7 in Group II recites a specific two antennas for selecting one of the two antennas by comparing an RSSI and a previous estimated signal level at the second antenna to provide an antenna diversity indicator indicative of a selection of the two antennas. The method claim 13 in Group III recites a specific slecting gain control paths for selecting one of the three selecting gain paths with an RSSI to define a current signal level and updating a low and high gain accumulators based on the current signal level. The inventions of the three groups are therefore seen to describe different special technical features in the three groups.